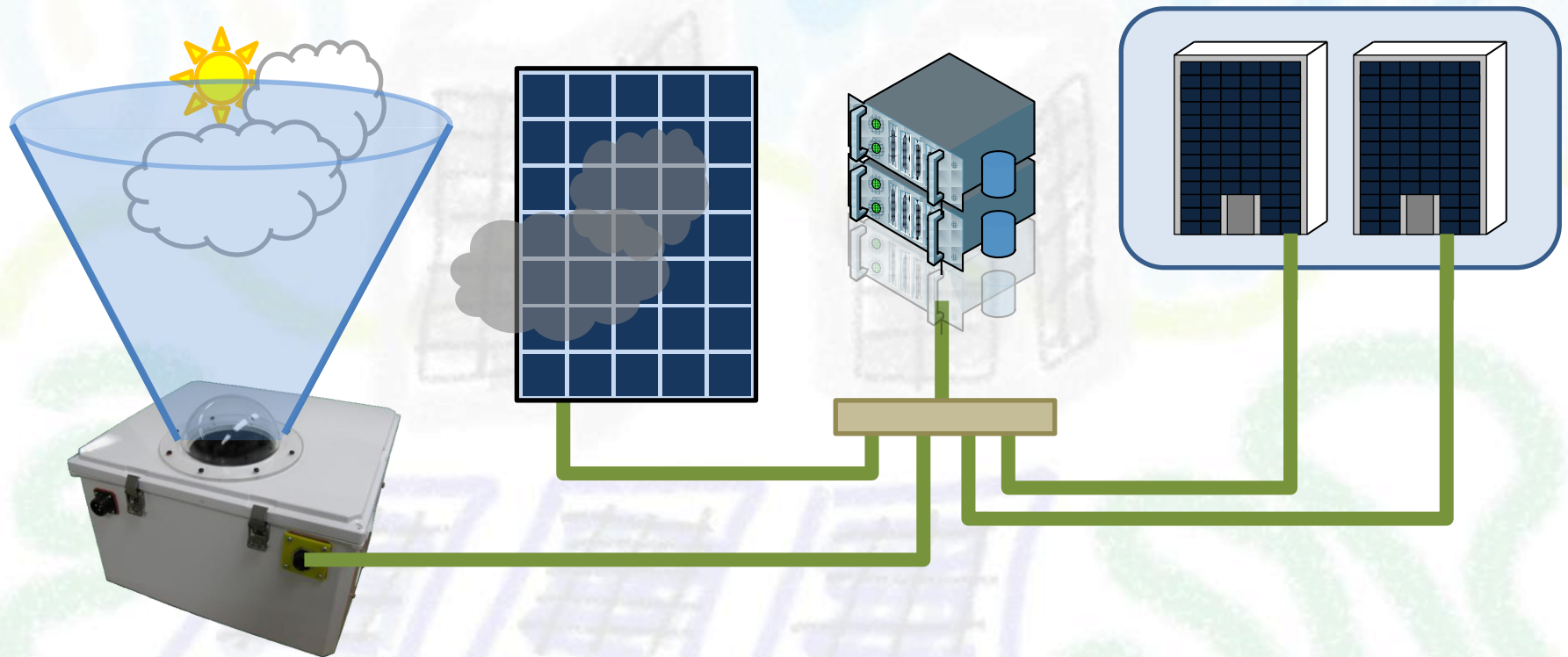


Sky Imager Solar Forecasting for Microgrid Optimization



Bryan Urquhart

November 16, 2011



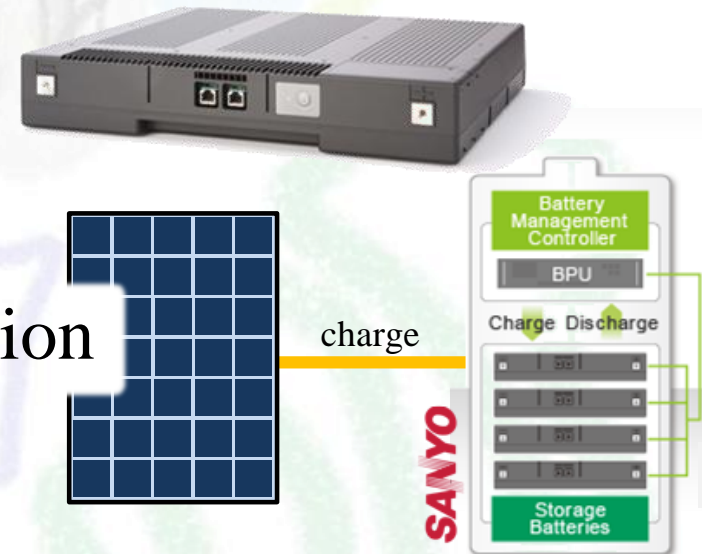
Why Solar Power?

- Reduce reliance on fossil fuels
- Reduce energy imports
- Renewable Portfolio Standards
- Compared to wind:
 - Better co-location near loads (distributed PV)
 - Output more predictable
 - Better correlation to load peak → more valuable power
 - But: higher energy production cost



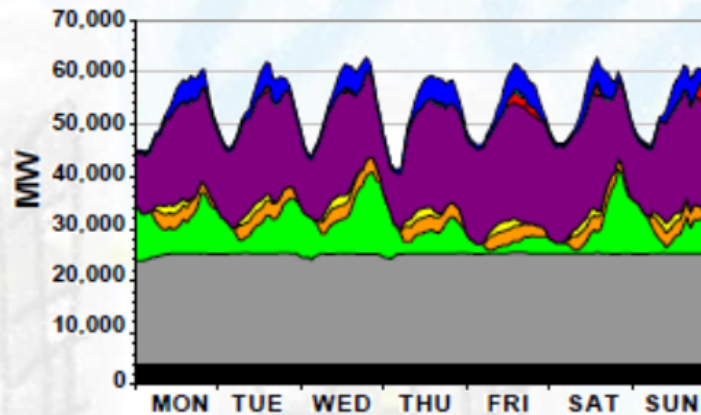
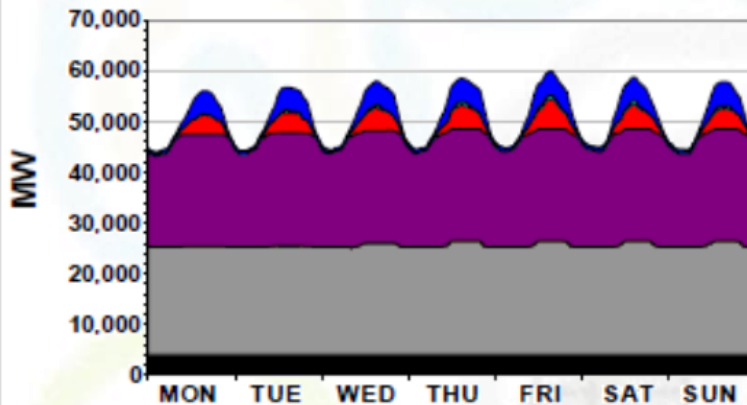
Why Solar Forecasting?

- Variable resources require reserve power
- Grid Operation
 - Forecasts can help to determine how to schedule generation and orchestrate power transmission
- Smart grid optimization
 - solar power production forecasts as input for generation scheduling
- Solar + Storage system optimization



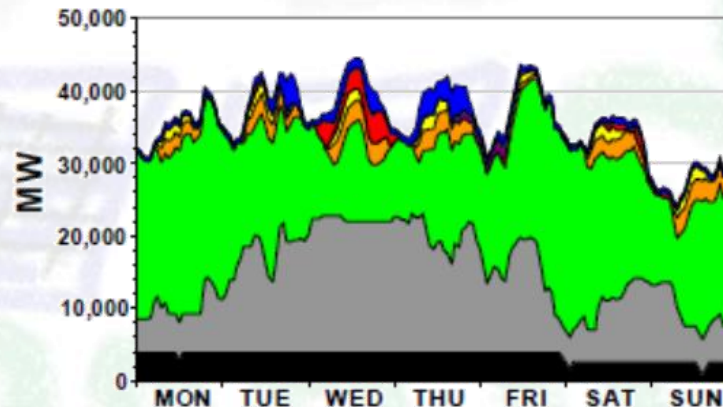
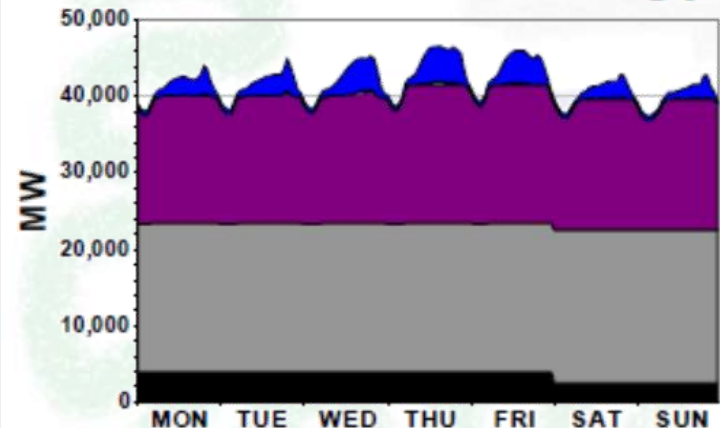
Renewables on the grid (35%)

SUMMER



easy week:
- large load
- small renewables

SPRING



hard week:
- small load
- large renewables

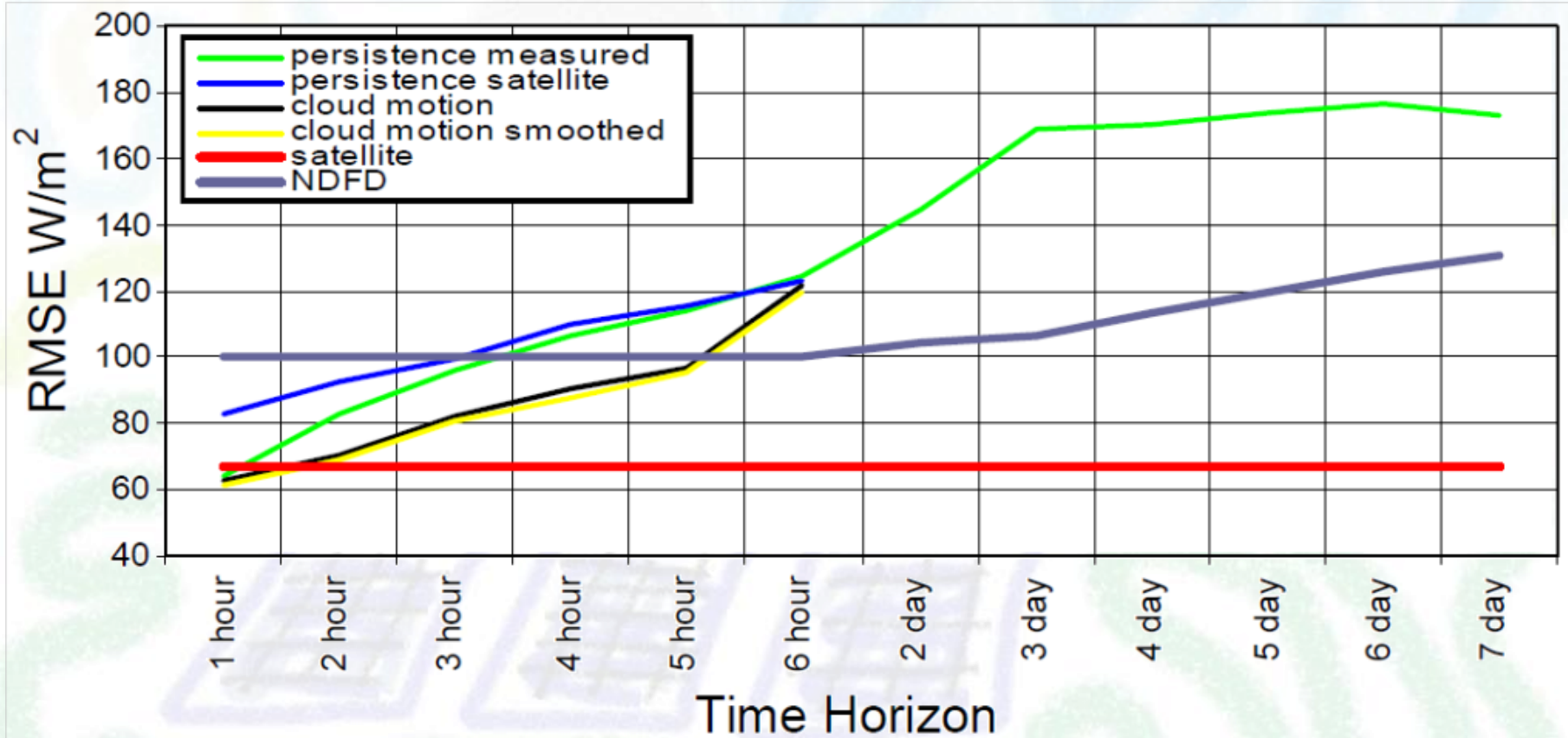
Solar Forecasting

- Solar forecasting critical for renewables integration
- Wind forecasting established (yet difficult); for solar:
 - different techniques required: weather models cannot resolve clouds
 - shortage of solar ground measurements

Technology	Forecast Horizon	Spatial Resolution	Spatial Coverage
Meteorological Models	> 5 hrs	3 km horizontal	Global/Continental
Satellite Imagery	30 min - 5 hrs	1 km ² at nadir	Continental
Network of point sensors	up to 5 hrs	–	–
Sky Imager	30 sec - 30 min	100 m ²	15 km ²



Solar Forecast Performance

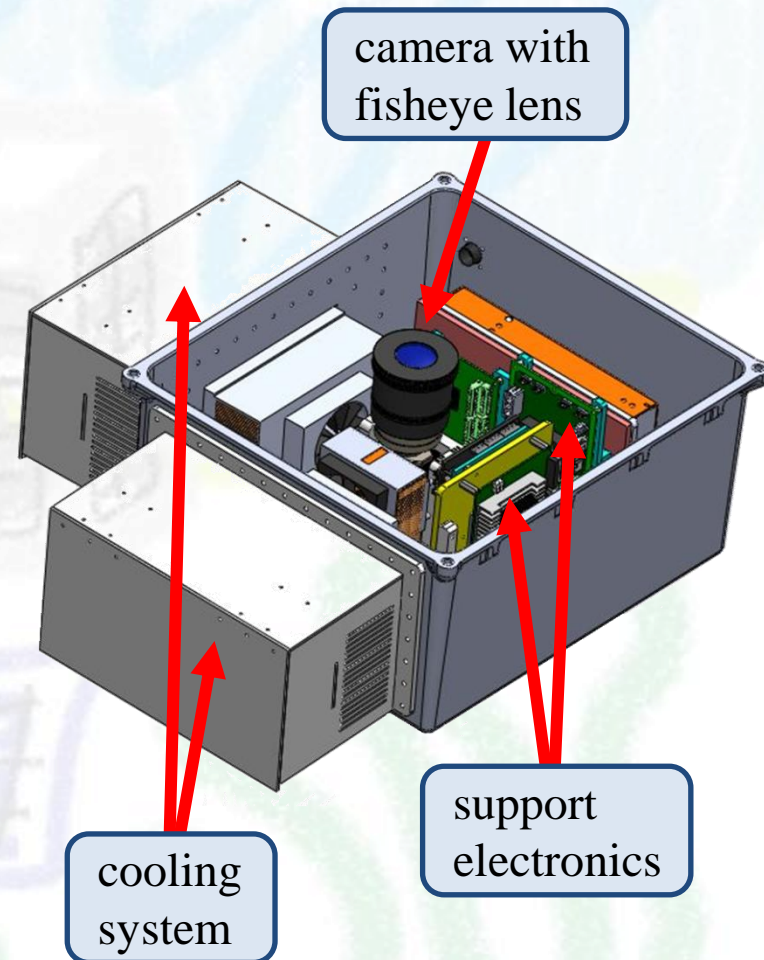
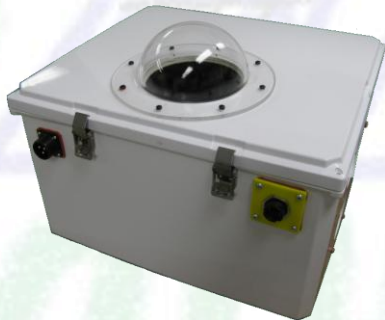


adapted from: Perez et al. (2010)



Ground-Image Based Forecasting

- High time resolution coverage
 - Limited by computing power
- Granular spatial resolution
 - Multi-megapixel cameras
- Reasonable coverage
 - $\sim 15 \text{ km}^2$ - cloud field dependent
- Short time-horizon
 - 10 to 20 minutes





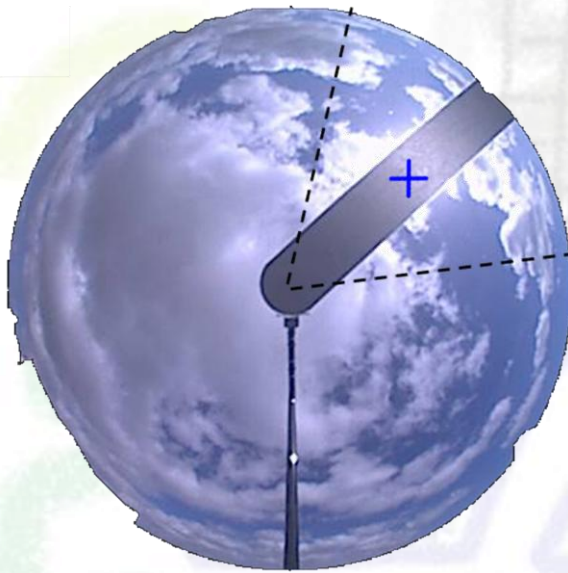
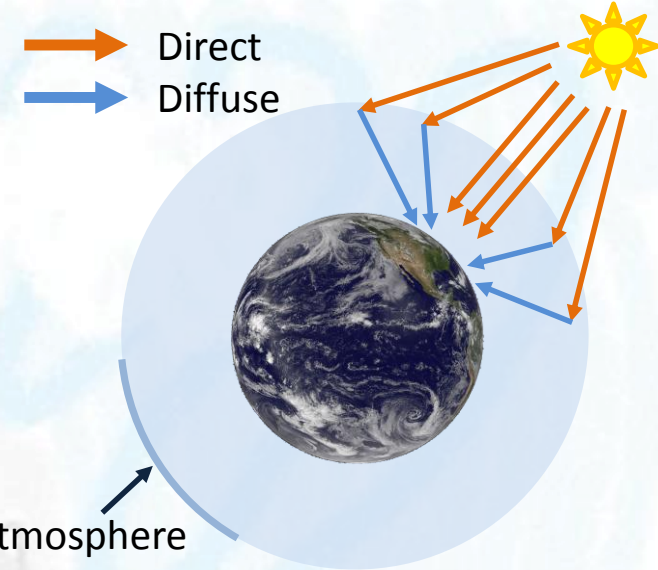
UC San Diego Sky Imager

October 4, 2009 11:20:30

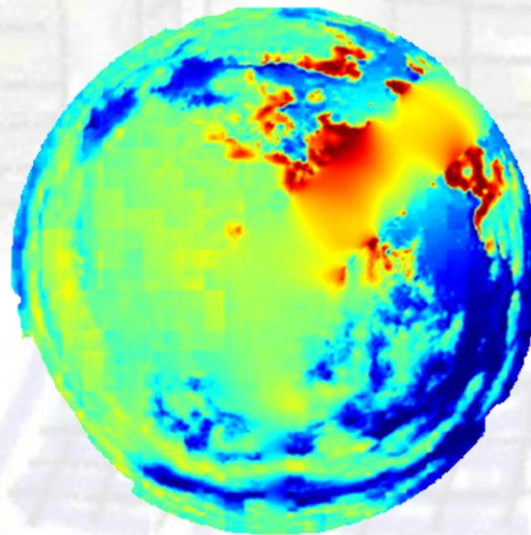


Cloud Decision

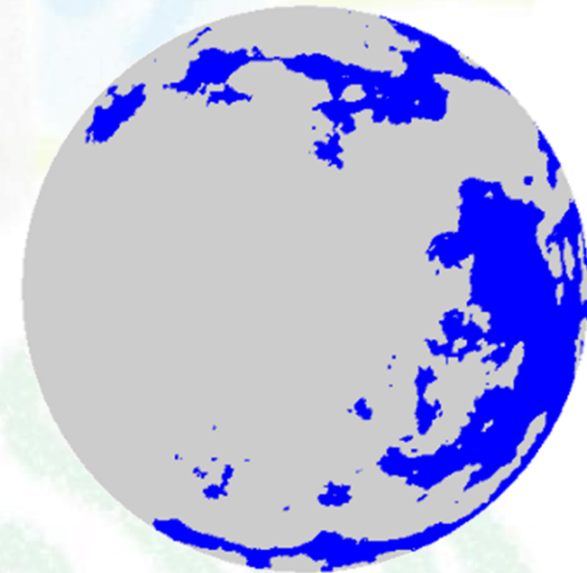
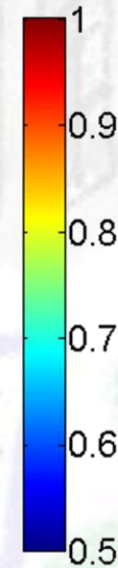
- Ratio of red content to blue content
 - Small values indicate clear sky
 - Values near unity indicate cloud



raw image



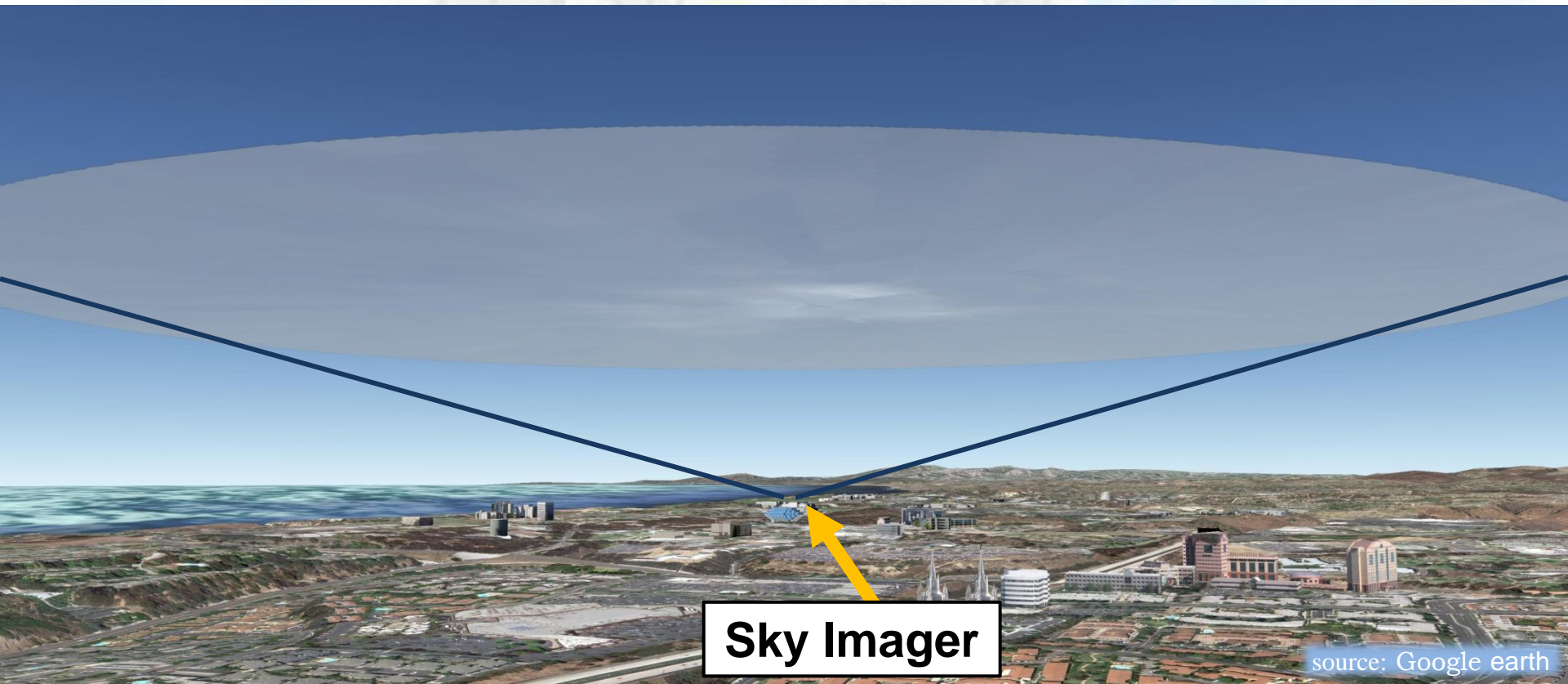
red-blue ratio



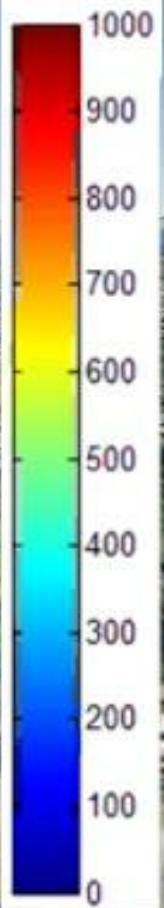
cloud decision

Cloud Mapping

- Cloud projection
 - Plane formed by cloud base
 - Ceilometer used for height



W/m²
for icons:
200

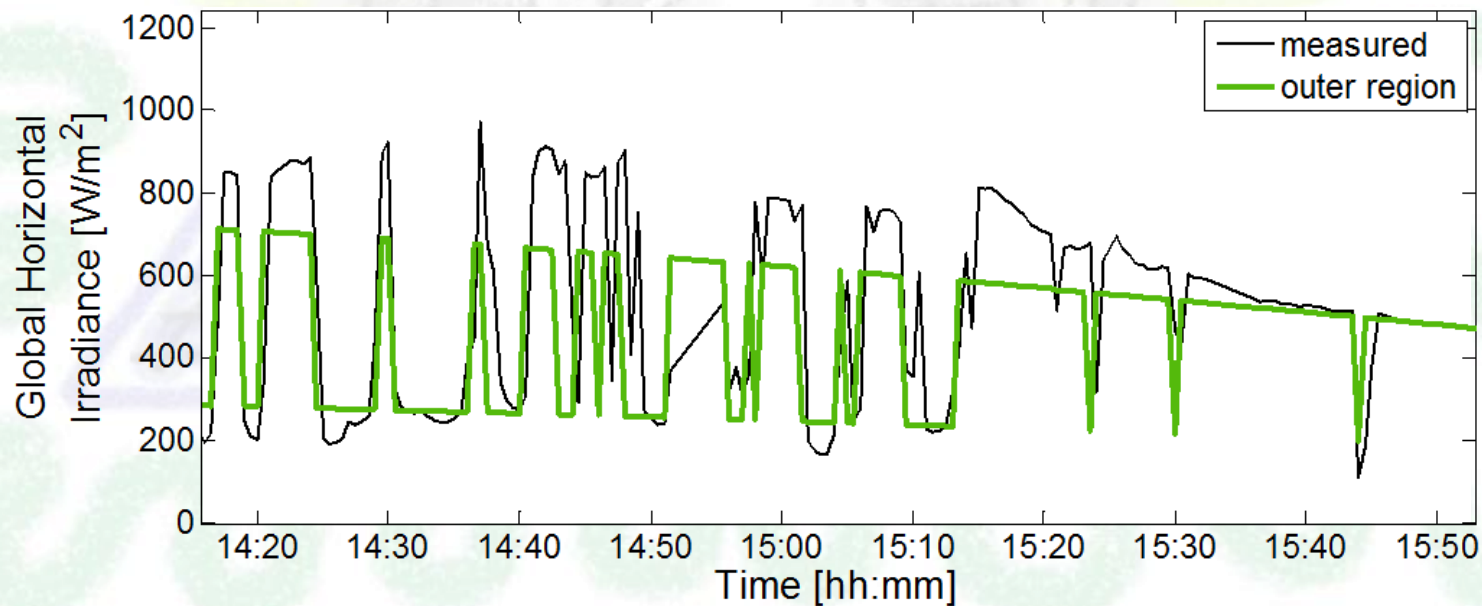
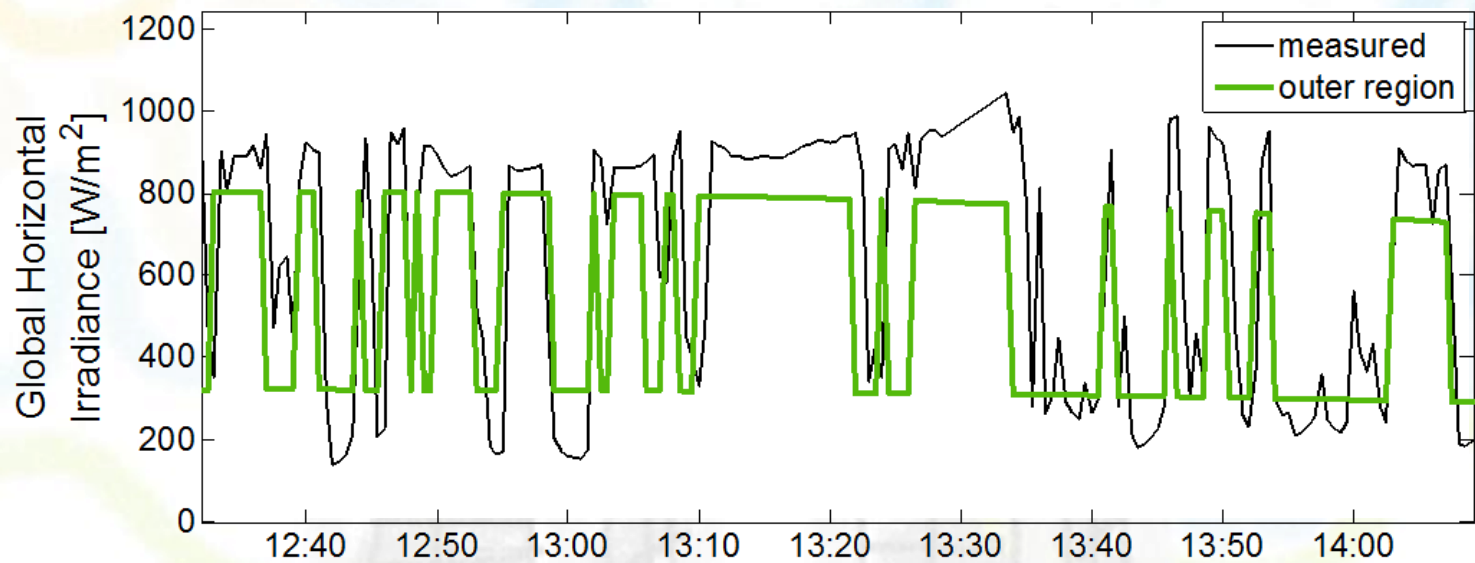


700 Weather Station [W/m²]
50 PV Array [kW]

Image © 2010 DigitalGlobe
Image © U.S. Geological Survey
Data SIO, NOAA, U.S. Navy, NGS, GEBCO

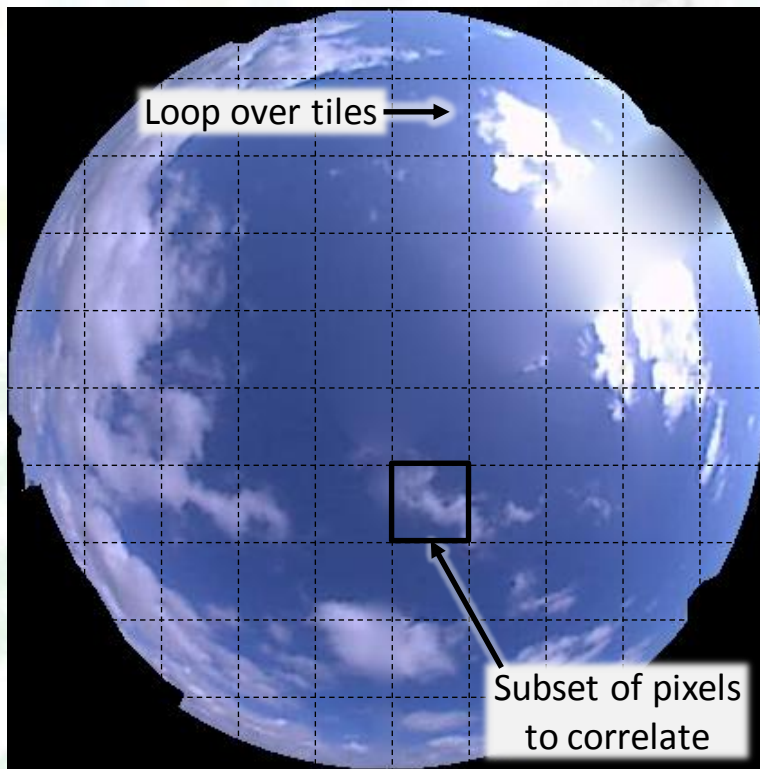
Google

Capturing ramps

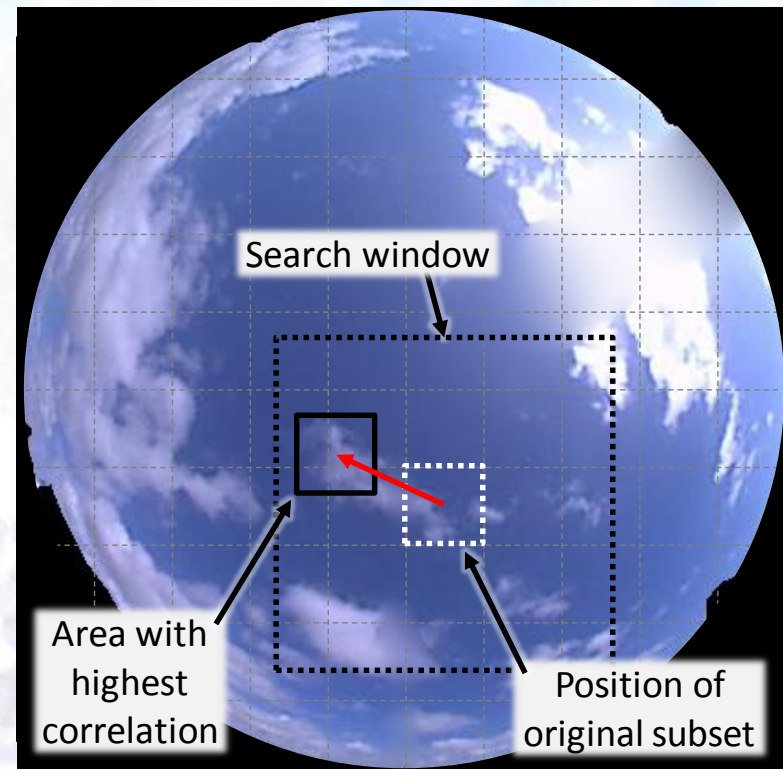


Cloud Motion

- Cross correlate image subsection within prescribed neighborhood

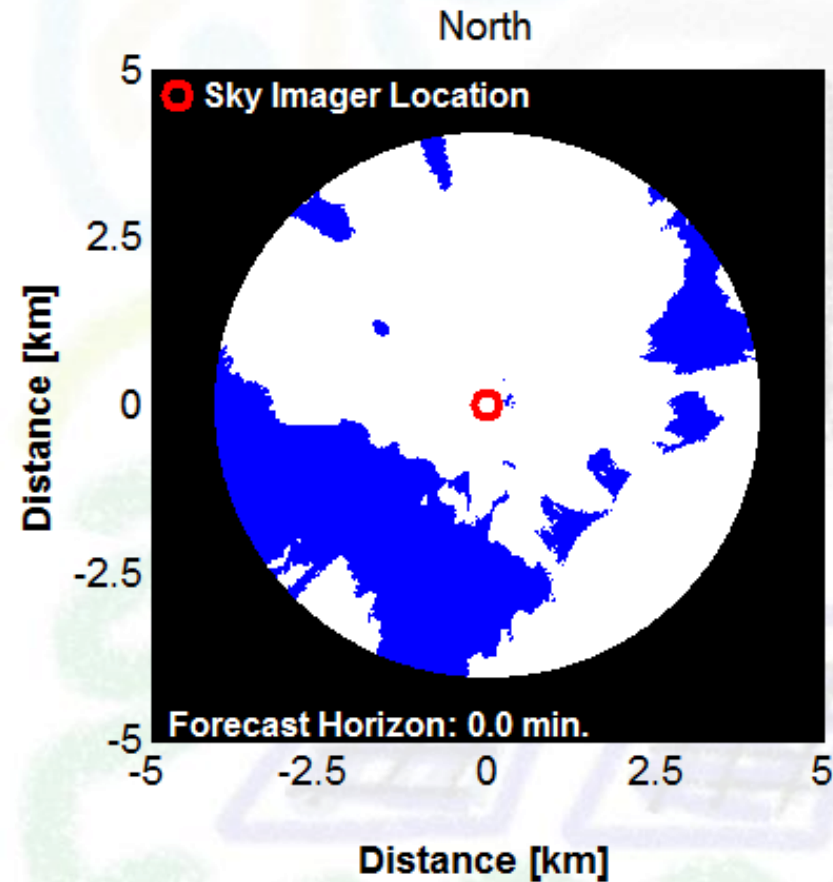


$t = t_0 - 30 \text{ sec.}$

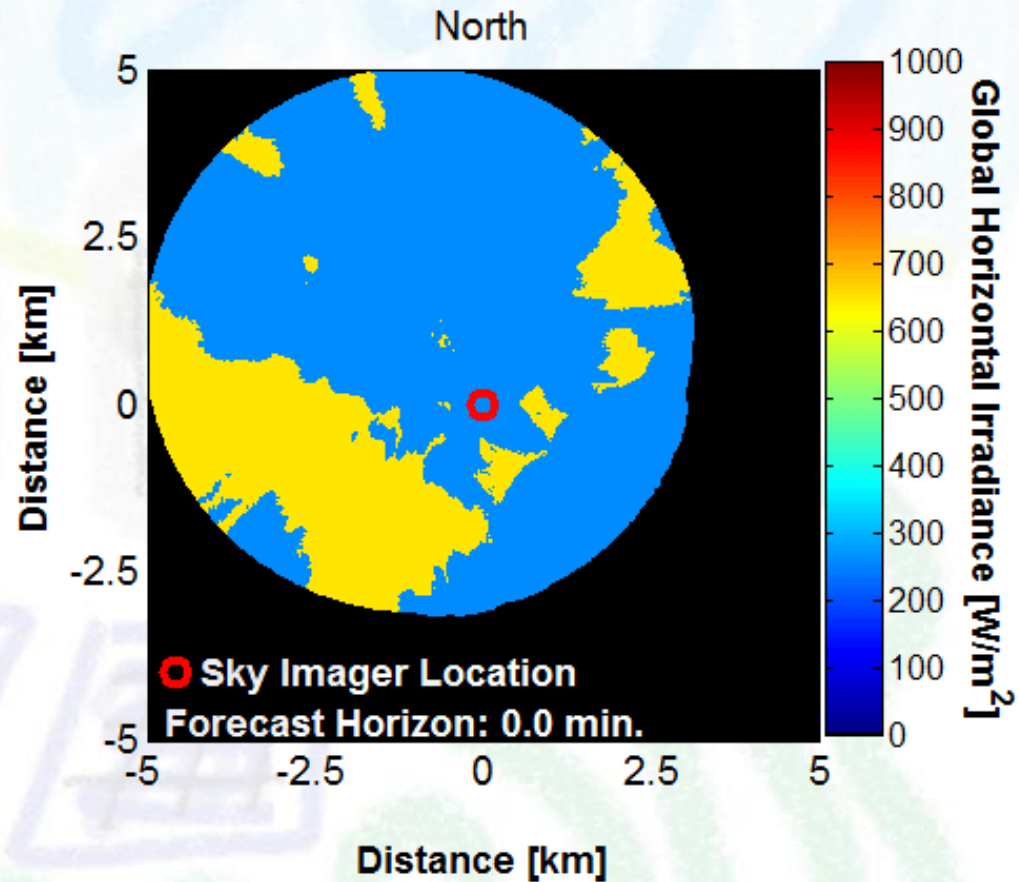


$t = t_0$

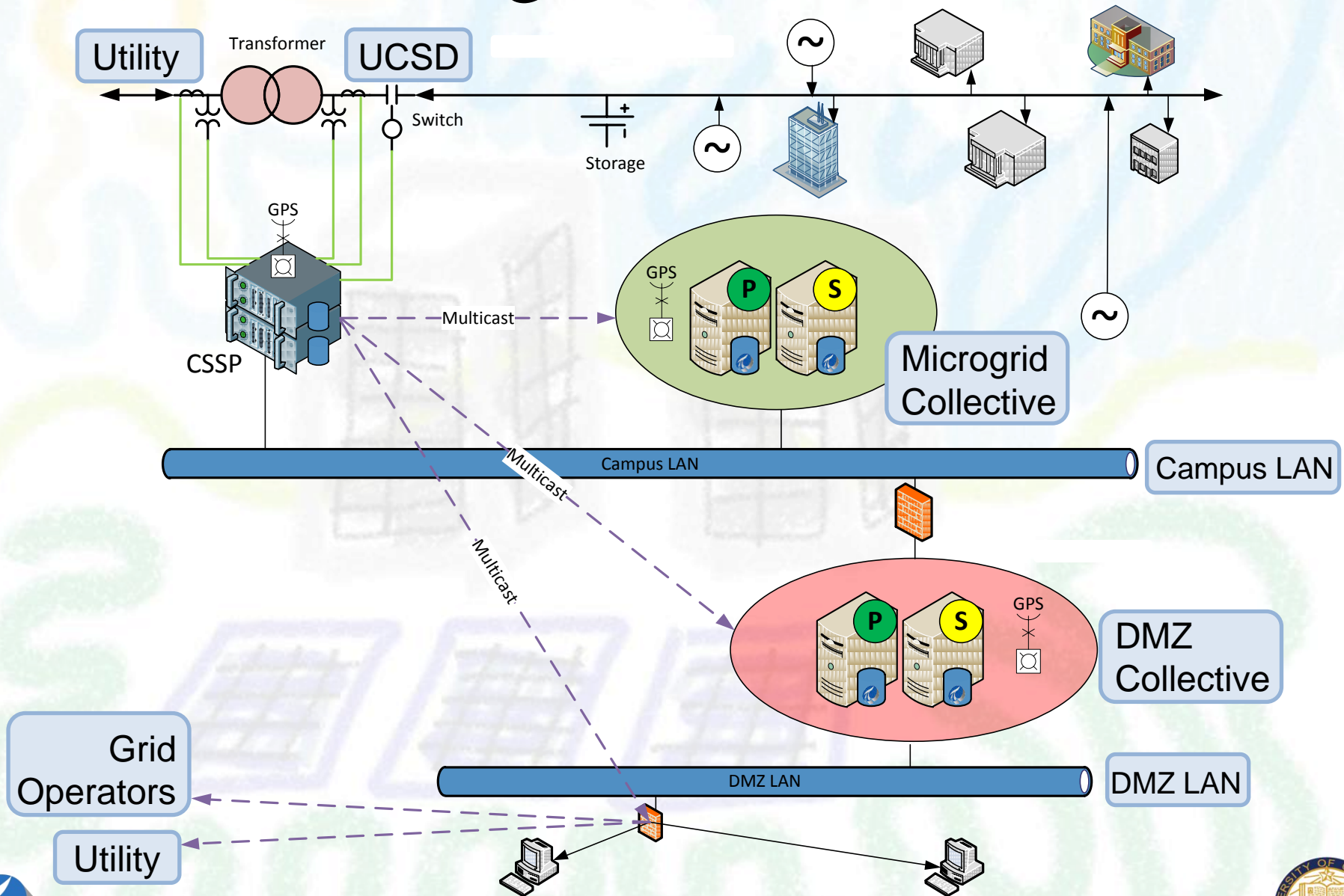
Cloud Map



Ground Irradiance Map



UCSD Microgrid



UCSD Microgrid – Living Laboratory

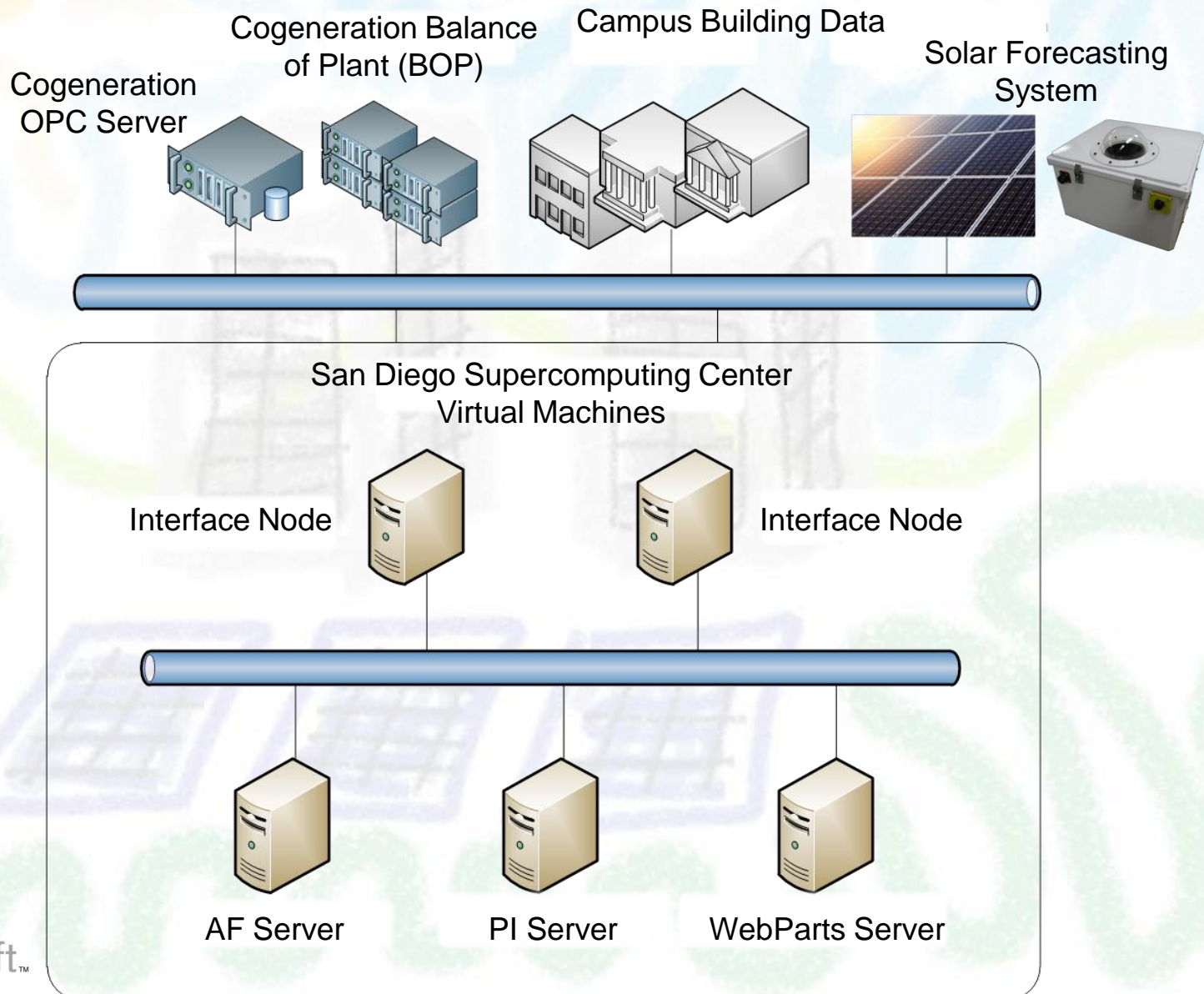
- Generation:
 - 42 MW peak load
 - 30 MW NG CCHP plant generates 80% of annual demand at 61% efficiency
 - 1.2 MW of PV
 - 40,000 ton hr thermal energy storage
- Distribution:
 - Owns 69 kV substation
 - 96× 12kV underground feeder circuits 4 × 12kV distribution substations
 - Meters 50,000 energy data points
- Committed to:
 - Power Analytics / Viridity Scheduler/Optimizer
 - 2.8 MW fuel cell using methane gas
 - 1.8 MW / 11.2 MWh electric energy storage
 - 1.9 MW expansion of PV with CREBs financing
 - 2.0 MW / 8 MWh of PV integrated storage with CA SGIP incentives
 - \$250M/yr building expansion and \$72M, 3 Yr EE program

Current Infrastructure

Planned Expansions



Microgrid Architecture



Microgrid Modeling and Simulation

- Entire campus has been modeled
 - Including PV arrays
- Optimizer aggregates over 67,000 signals and generates a set of schedules for the next hour
 - Includes solar power forecast
- Simulator runs schedules and checks for violations of power quality
- Control software engages changes according to the selected schedule
- Collaborative University and Industry Effort
 - UCSD, OSISoft, Power Analytics, Viridity & U.S.DOE

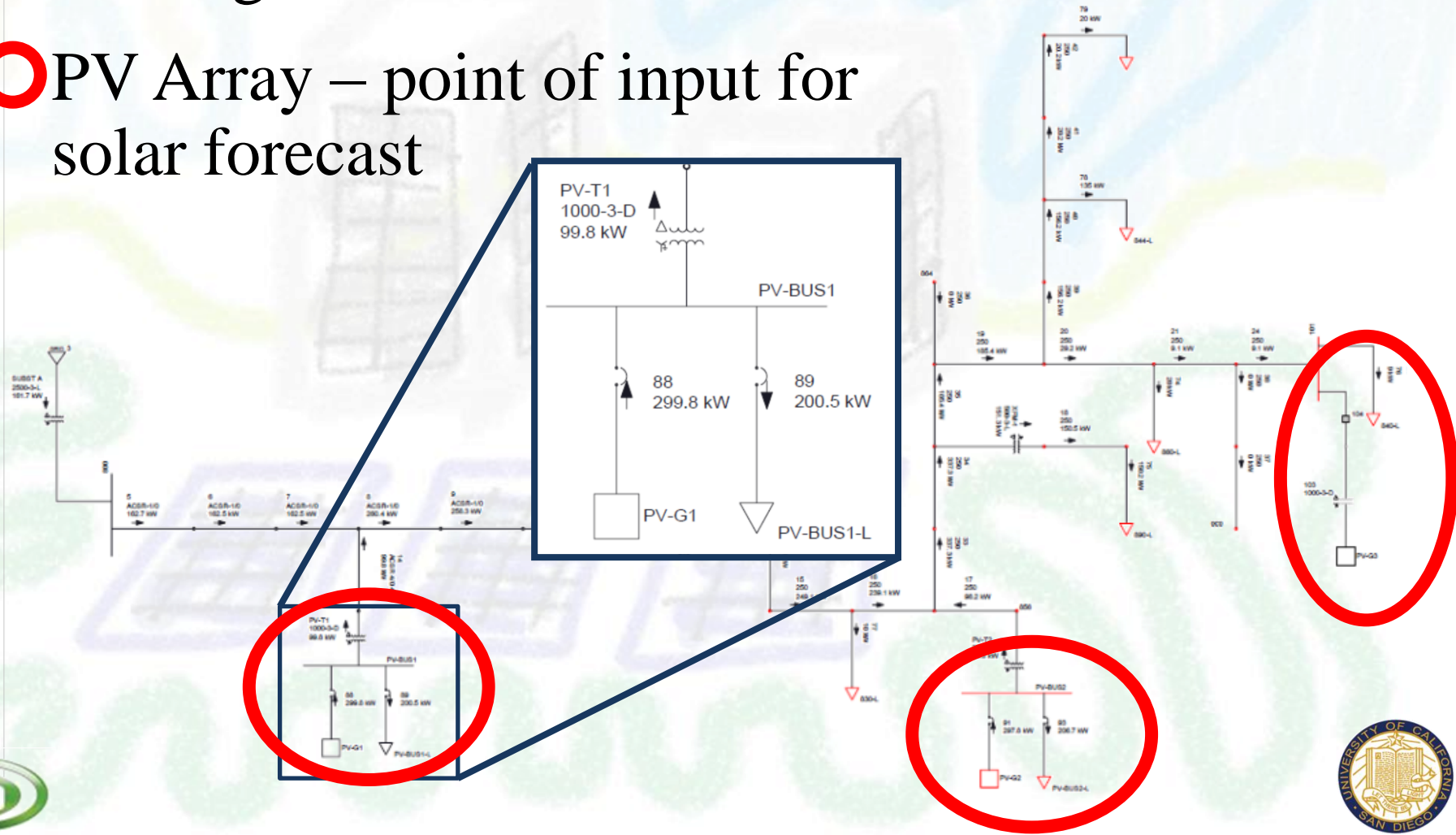


Model for building, 330 kW PV

- Parking structure with solar trees

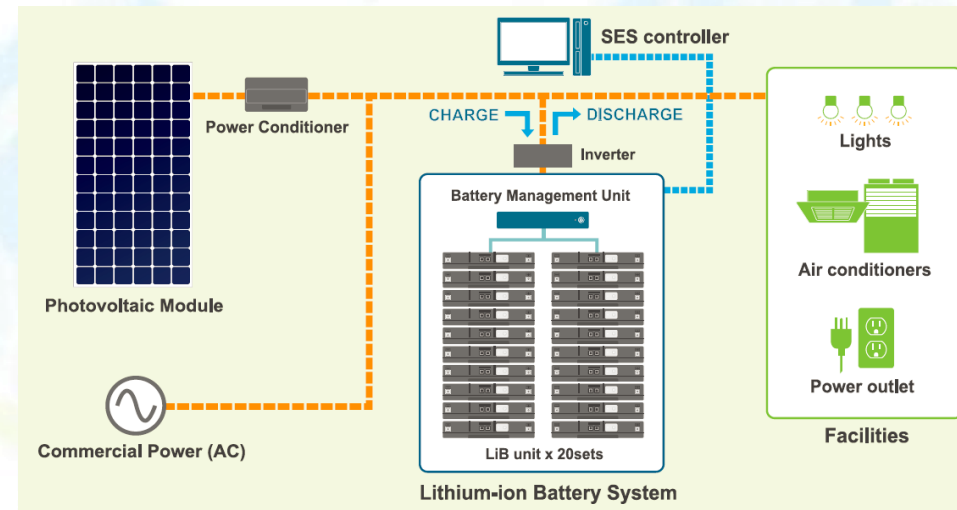
○ PV Array – point of input for solar forecast

Gillman Parking Structure



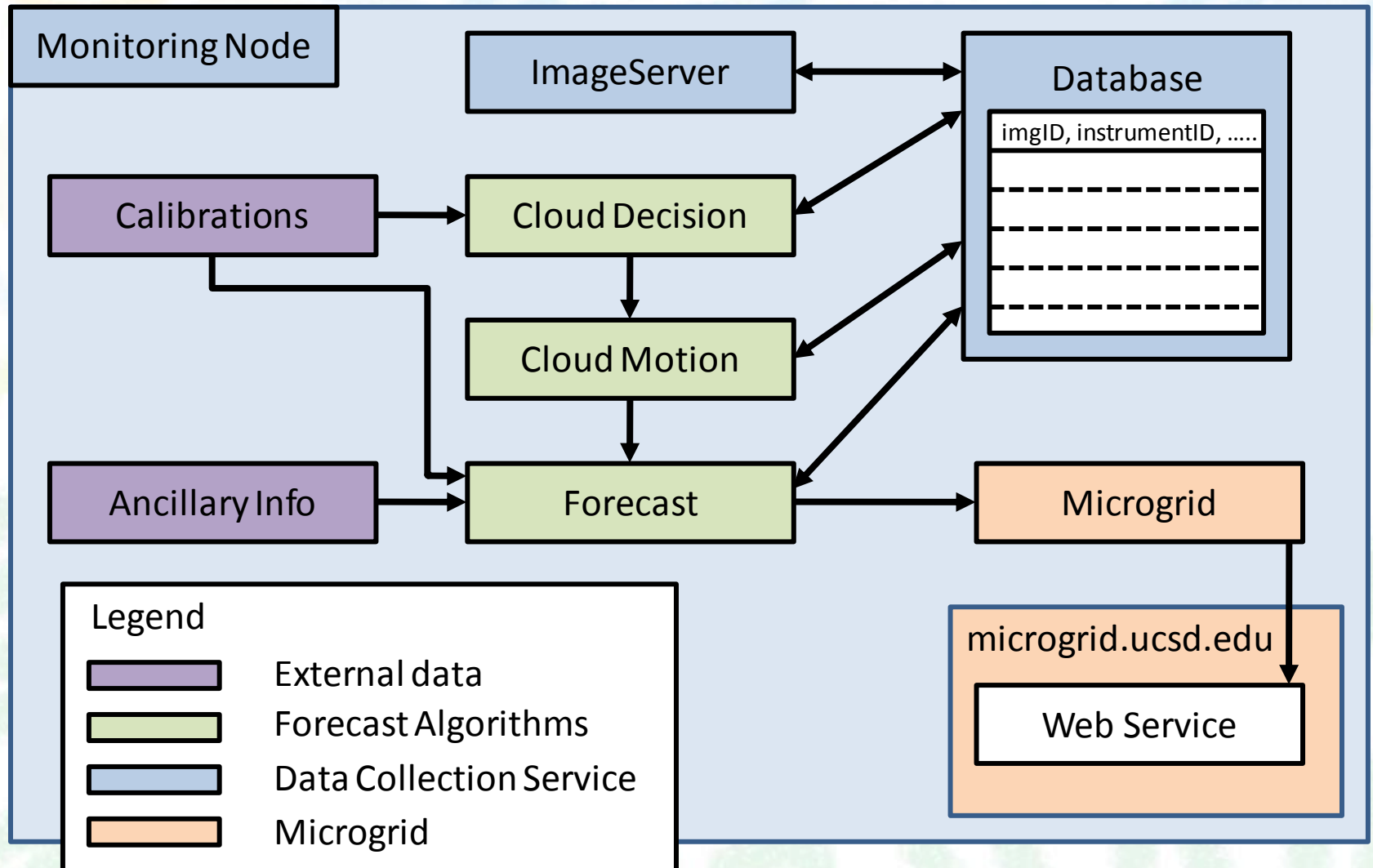
Sky Imager for Storage Optimization

- UCSD and Sanyo have partnered on a 31.5kW PV + 31 kWh Li-ion storage system
 - UCSD provides solar forecast input for charge/discharge optimization



	Optimization with PV Power Output and Load Forecast	Off-Peak/On-Peak without PV Power Output and Load Forecast
Annual Energy Bill Cost Reduction [\$]	33,200	30,500
Number of Cycles at 80% DoD [cyc/yr]	212	365
Battery Lifetime [yrs]	14.2	8.2
Fixed Cost Simple Payback Time [yrs]	5.7	6.2
Total Profit at End of Battery Lifetime (Annual Energy Bill Savings x Battery Lifetime – Fixed Costs) [\$]	281,000	60,000

UCSD Operational Forecasting



Acknowledgements



Thank you for your time



visit us: solar.ucsd.edu
microgrid.ucsd.edu



Clancy Energy > Salt Creek Field Production



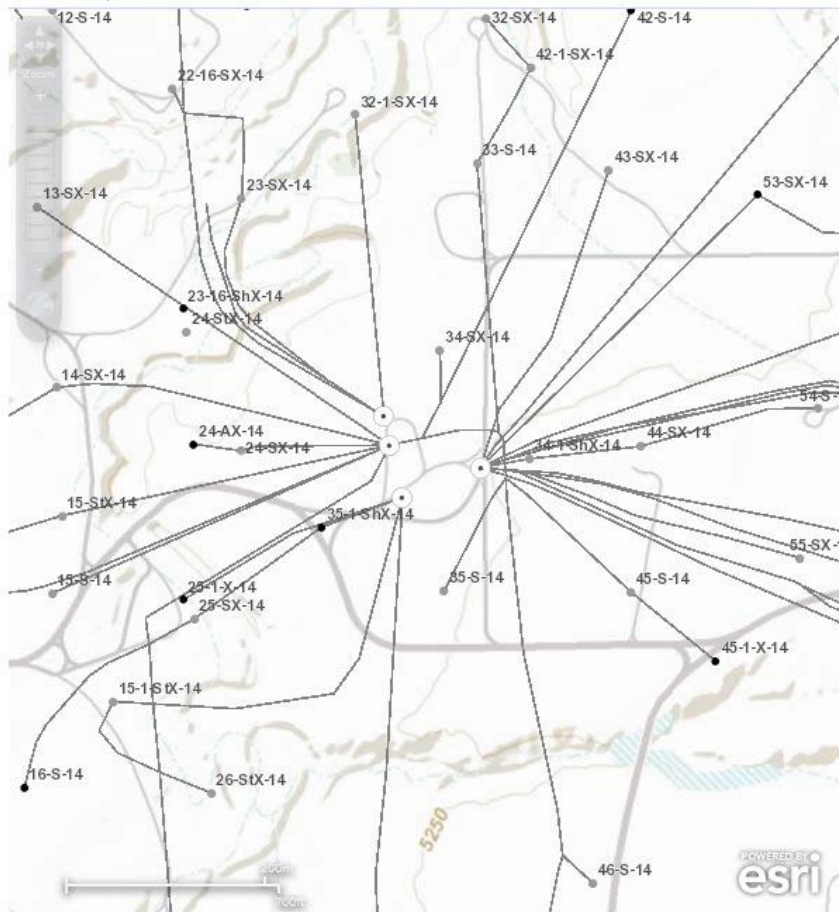
Home Salt Creek Field Production Environment, Health and Safety

Search this site...

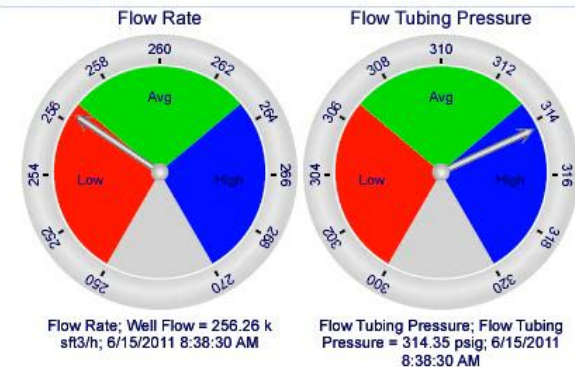
PI TreeView

- Facility
 - Antelope Creek
 - Buffalo Draw
 - Elk Meadows
 - Jackrabbit Run
 - Porcupine Creek
 - Possum Gulch

ArcGIS Map



PI Gauge



PI Trend



PI TimeRange

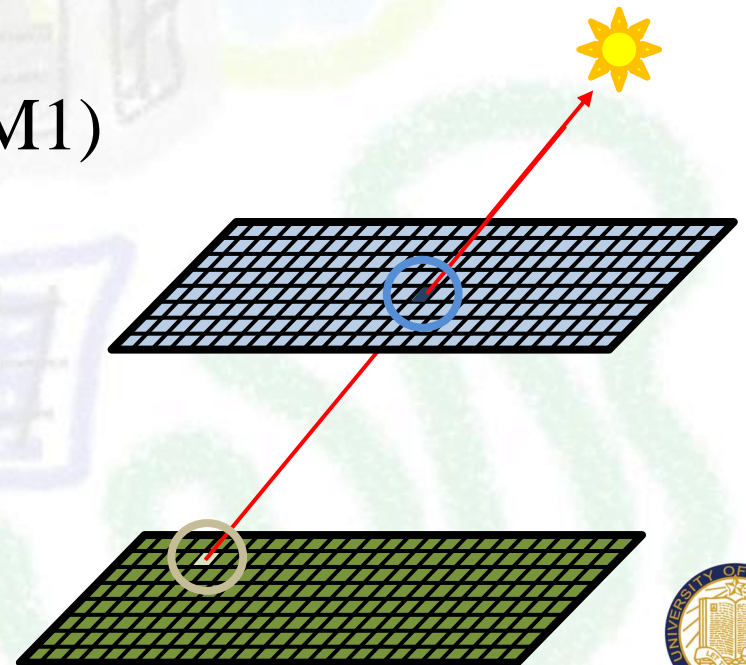
Start Time *2h End Time * Apply

Flow Rates of Multiple Wells

Cloud Shadow

- Shadow is projected to ground from binary cloudmap using solar angles
 - binary: clear or cloudy
- Sky condition mapped to ground (“shadowmap”)
 - 10×10 m grid cells
 - Topography included (SRTM1)

topography not
shown in shadowmap
illustration



Sky Condition Forecasting

- Binary cloudmap \rightarrow binary comparison metric
 - Condition is **clear** or **cloudy**
- Sky imager derived condition determined from projected cloud shadows
- For pyranometer measurements:

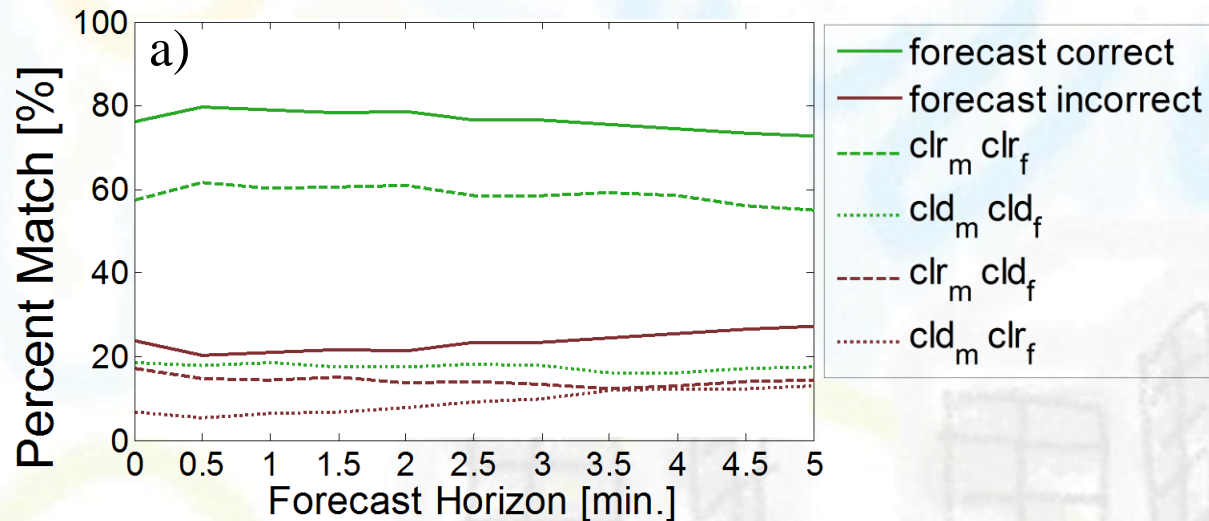
$$\begin{aligned}
 \text{clear} &\equiv kt > 0.7 \\
 \text{cloudy} &\equiv kt \leq 0.7 \quad , \quad kt = GHI / GHI_{csk}
 \end{aligned}$$

- Four possible outcomes:

Measured	Sky Imager Forecast		match:
	Clear	Cloudy	
Clear	clr_mclr_f	clr_mcld_f	Positive
Cloudy	cld_mclr_f	cld_mcld_f	Negative

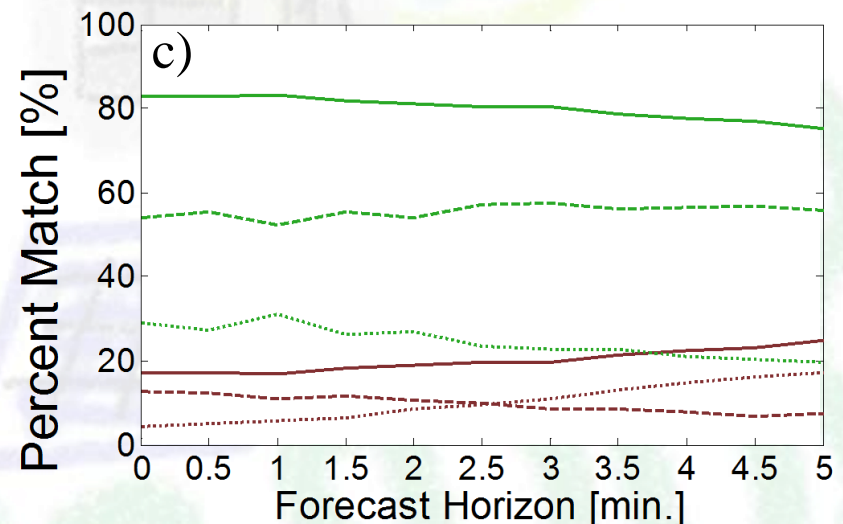
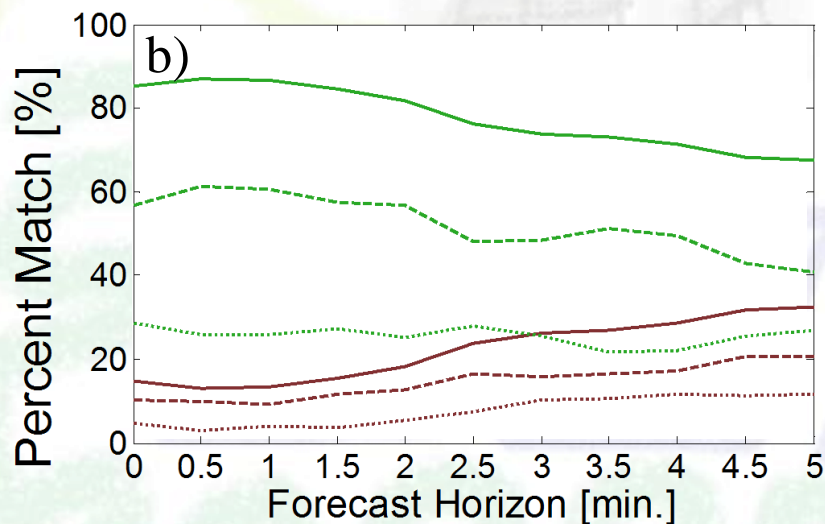


5-min Forecast Results



- a) All 4 days[†]
 b) October 4, 2009
 c) March 10, 2010

Sky Imager Forecast		
Measured	Clear	Cloudy
Clear	$\text{clr}_m \text{clr}_f$	$\text{clr}_m \text{cld}_f$
Cloudy	$\text{cld}_m \text{clr}_f$	$\text{cld}_m \text{cld}_f$



[†]includes September 15, 2009 and March 04, 2010

